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SESSION ID: TPV-T02

Repeatable Supply Chain Security Failures in Firmware Key Management

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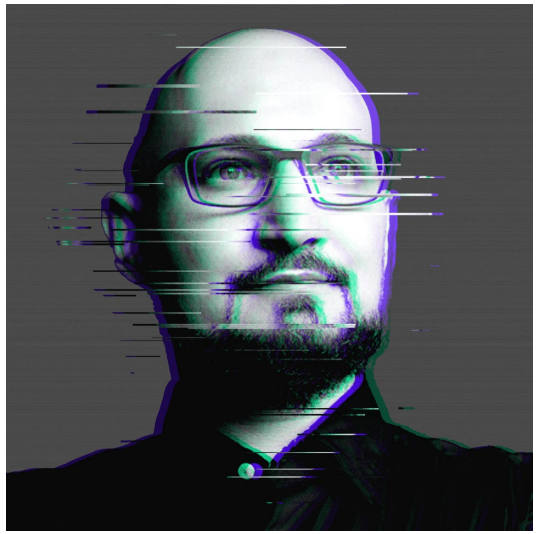
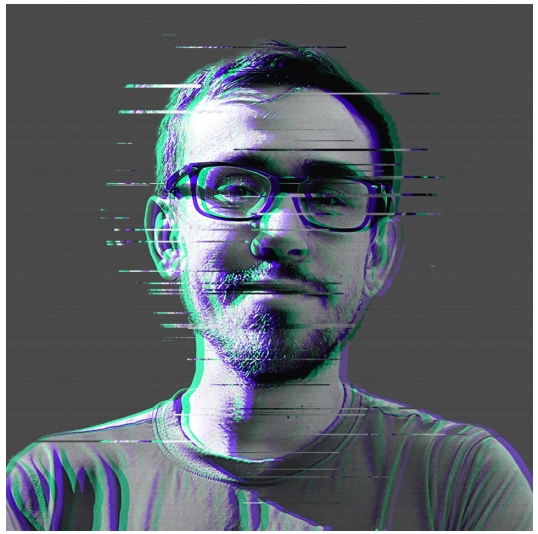
Binarly REsearch Team





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https://www.binarly.io/articles
https://www.binarly.io/advisories

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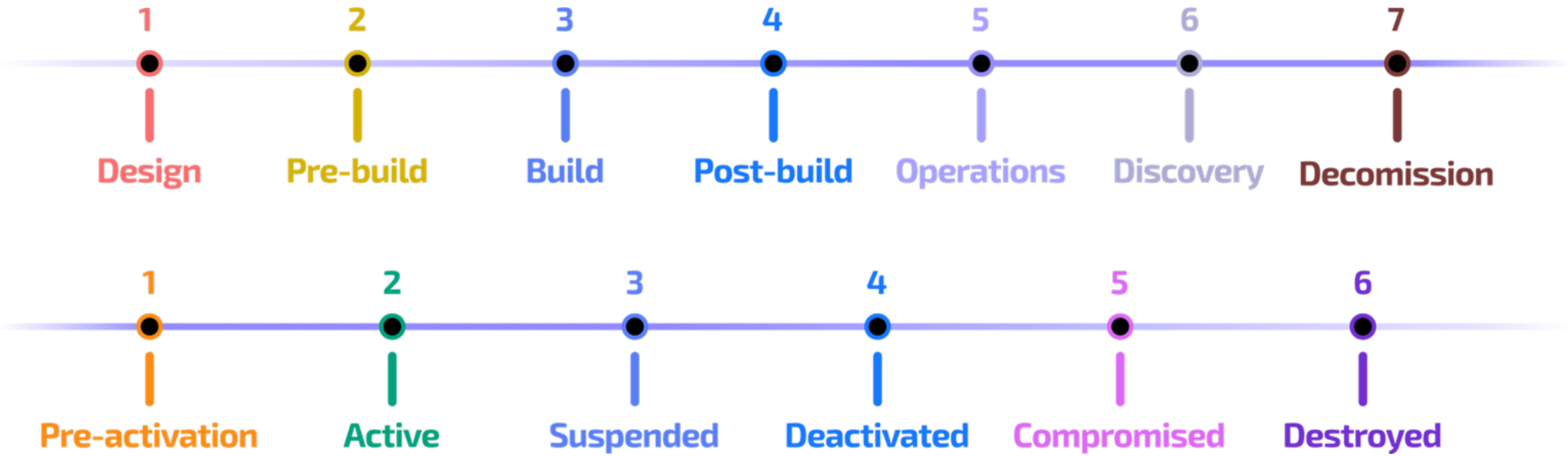
All this has happened before.
All this will happen again.

Cryptographic Key Management is Hard!



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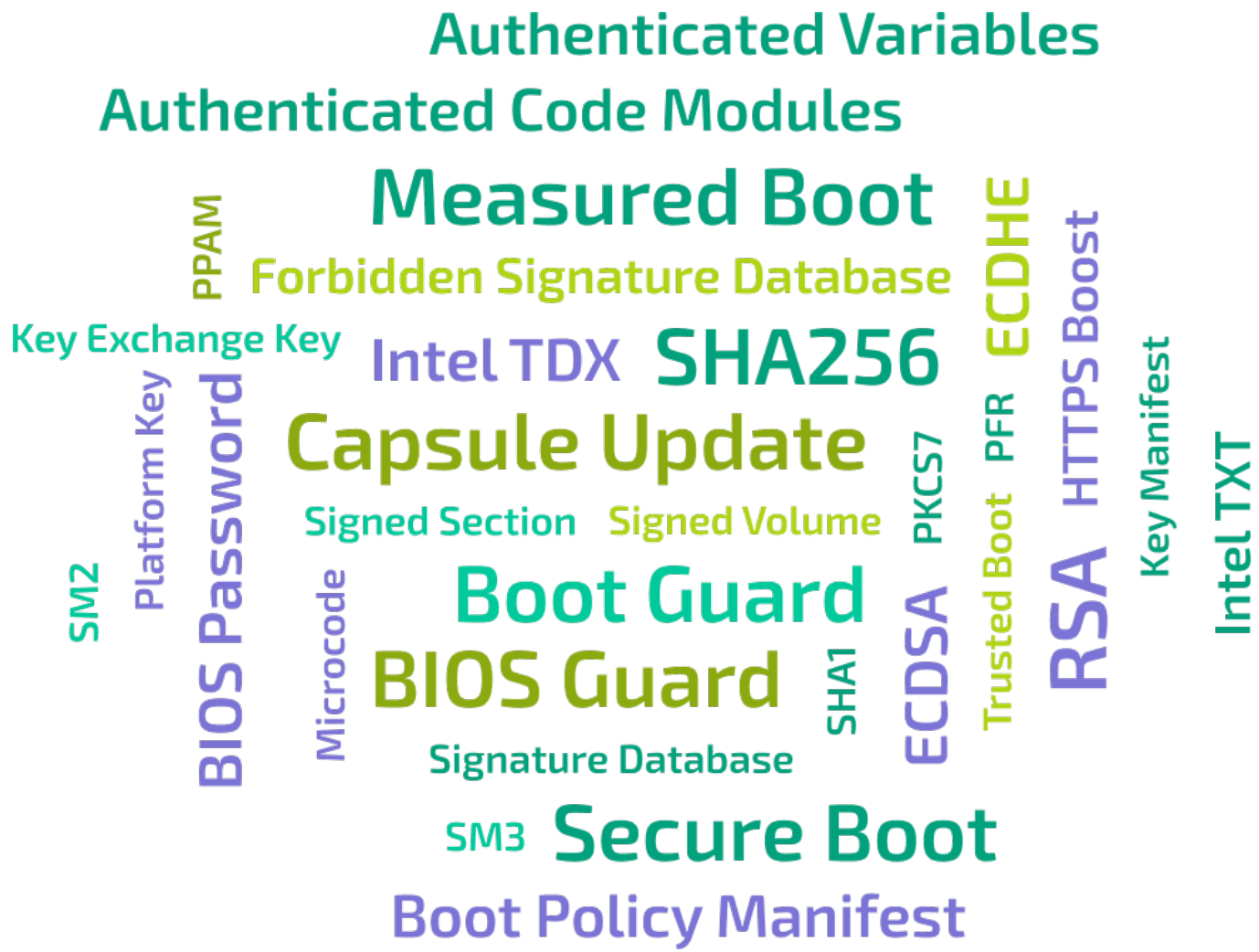
Introduction



Introduction

What can go wrong?

Security risks arising from firmware developer and device vendor breaches

2022

- Intel PPAM expired certificate
- LC/FC data breach

2023

- MSI OEM data breach
- Intel BootGuard key leakage impact

2024

- PKfail + BlackLotus Demo
- Supermicro

2025

- DBX inconsistency
- Intel BootGuard again?
- AMD Microcode validation is broken

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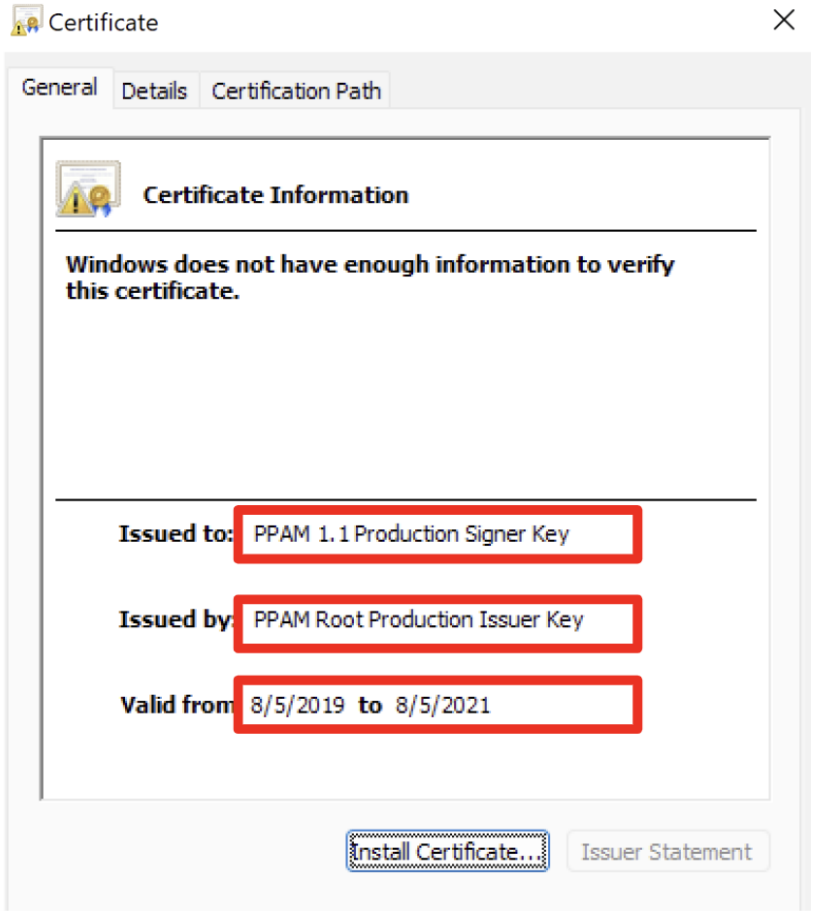
[2022] Intel Platform Properties Assessment Module (PPAM) Expired Certificate Story

[2022] Intel PPAM expired certificate

- Platform Properties Assessment Module (PPAM) measures the integrity of SMM code
- Binary signed by Intel that runs before System Management Mode (SMM) entry point
- PKCS7 certificate provides a digital signature for PPAM
- Multiple devices with expired PPAM certificate

https://www.binarly.io/blog/black-hat-2022-the-intel-ppam-attack-story



Revisiting Intel PPAM expired certificate

- Retrospective scan on our dataset revealed that 68% of certificates in-the-wild are expired
- We also found few recents devices deployed with PPAM debug certificates
- This is not a security vulnerability, but shows the bad security practices

```
Version: 3 (0x2)
Serial Number:
    63:00:33:3a:47:12:7f:a3:eb:ad:a1:61:ad:00:01:00:33:3a:47
Signature Algorithm: sha256WithRSAEncryption
Issuer: C=US, ST=CA, L=Santa Clara, O=Intel Corporation,
        OU=SSG, CN=PPAM Root Debug Issuer Key
Validity
    Not Before: Jun 12 10:59:01 2019 GMT
    Not After : Jun 12 10:59:01 2020 GMT
Subject: C=US, ST=CA, L=Santa Clara, O=Intel Corporation,
         OU=SSG, CN=PPAM 1.1 Debug Signer Key
Subject Public Key Info:
    Public Key Algorithm: rsaEncryption
        Public-Key: (2048 bit)
        Modulus:
            00:bf:ec:93:b2:59:0f:7f:ef:e1:cc:ae:bc:33:27:
            e5:34:e6:d8:eb:00:17:aa:51:65:56:74:e2:10:a5:
            19:dc:a1:89:74:ab:45:f1:0a:9a:5b:54:af:14:42:
...
```

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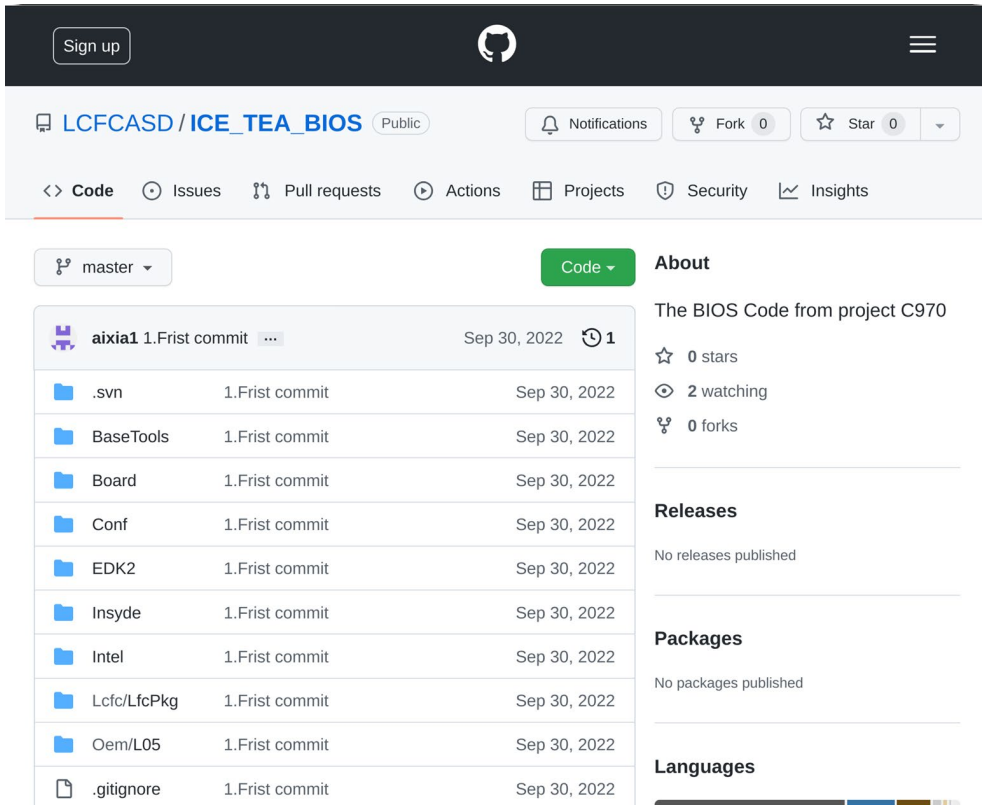
[2022] Lenovo LCFC OEM Data Breach and Leaked Keys

[2022] LC/FC data breach

- Alder Lake's UEFI firmware was leaked on GitHub
- Reference implementation (Intel), IBV solution (Insyde) and OEM implementation (Lenovo)
- 6GB of source code, binary blobs, debugging tools and multiple private keys

https://www.binarly.io/blog/leaked-intel-boot-guard-keys-what-happened-how-does-it-affect-the-software-supply-chain

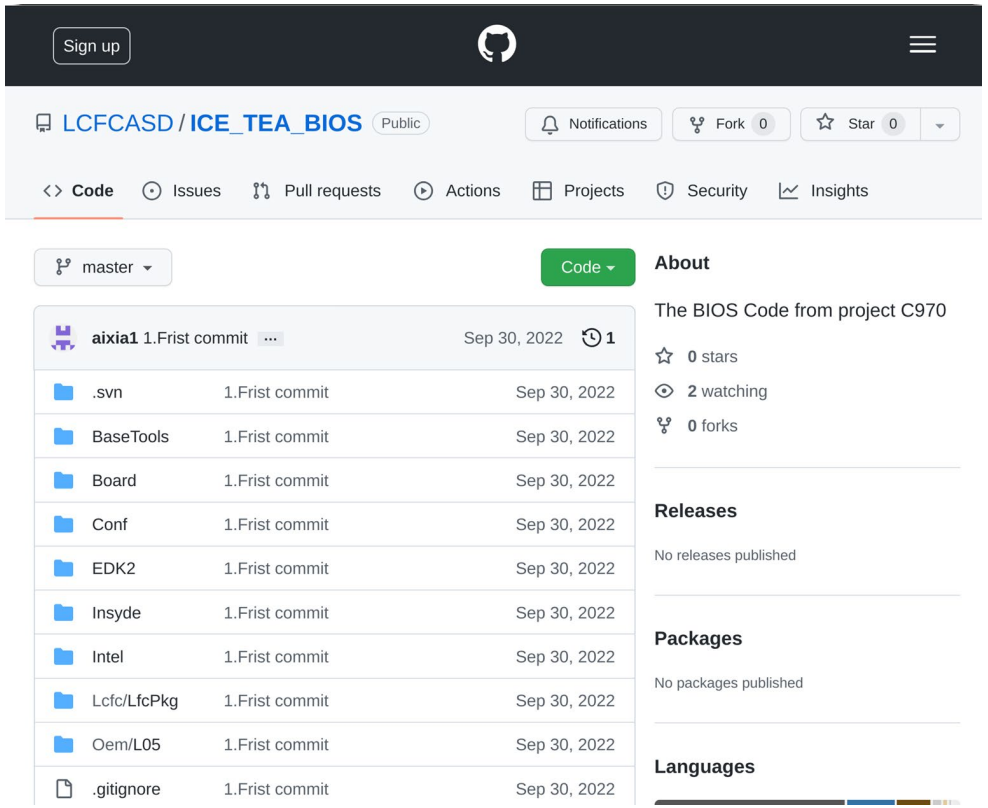


[2022] LC/FC data breach

Leaked private keys:

- Intel Integrated Sensors Hub (ISH) signing key
- Intel Boot Guard KM/BPM keys
  - Found on devices from Lenovo, Supermicro and Intel

https://www.binarly.io/blog/leaked-intel-boot-guard-keys-what-happened-how-does-it-affect-the-software-supply-chain



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[2023] MSI OEM Data Breach and Leaked Keys

[2023] MSI OEM data breach

- Breach from the Money Message ransomware group
- 1.5TB of source code, production databases and multiple private keys

https://www.binarly.io/blog/leaked-msi-source-code-with-intel-oem-keys-how-does-this-affect-industry-wide-software-supply-chain

[2023] MSI OEM data breach

- Intel BootGuard BPM/KM keys
  - More than 100 MSI devices affected
- FW Image Signing Keys
  - Around 60 MSI devices affected
- Intel OEM Platform Key
  - Orange unlock: more powerful than Boot Guard key
  - Found on devices from HP, Lenovo, AOPEN, CompuLab, and Star Labs

https://www.binarly.io/blog/leaked-msi-source-code-with-intel-oem-keys-how-does-this-affect-industry-wide-software-supply-chain

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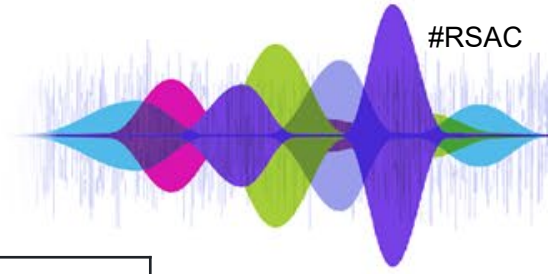
[2025] Clevo ODM Leaked Keys

[2025] Clevo Boot Guard keys leak

- Binarly was notified by Thierry Laurion about a possible leak of Boot Guard keys from Clevo in March 2025
- Firmware update package (400MB uncompressed size)
- Contains user manuals, internal tooling, firmware images and Boot Guard private keys

```
$ openssl rsa -text -in CreateDeleteBIOSKey.keyprivkey.pem
Private-Key: (3072 bit, 2 primes)
modulus:
    00:c5:81:81:14:d9:69:55:6c:38:a4:1a:f3:1c:a2:
    01:10:cf:02:f1:0c:73:f6:44:dc:e8:ae:25:69:6b:
    fa:14:ca:95:58:1a:d6:63:95:e4:97:57:a7:12:ea:
    eb:32:c8:b1:34:4b:1e:97:08:68:b9:7f:54:89:ba:
    09:86:cd:f1:1a:0d:e8:0d:18:38:e2:a0:bb:ad:87:
    d3:c2:3f:d5:e4:e8:4e:cd:e7:7d:d4:67:3b:33:ee:
    4a:ce:7c:aa:88:45:fa:ac:74:d1:a9:42:14:c7:1a:
    88:9c:cf:61:ef:b6:36:65:a7:2d:05:21:1e:a9:3a:
    fe:2d:09:09:0e:e7:e8:eb:e6:6e:61:95:11:a8:b5:
    78:b4:8c:0f:49:82:47:7b:87:b5:0d:a8:57:9f:16:
    12:8f:d8:ef:e6:84:49:f9:f7:37:a1:00:5f:4d:92:
    a9:e7:08:3c:bc:04:63:2f:94:49:1c:23:1f:72:dd:
    25:ed:bb:d1:92:69:11:2b:23:a4:72:02:89:e2:ab:
    93:e9:1f:e4:4a:f8:ac:bd:12:e7:69:3e:b9:a1:80:
    04:f8:2f:00:20:fd:15:12:2b:7d:f7:91:bc:33:84:
    bf:e1:e7:26:58:c3:00:29:02:f6:66:9e:69:68:f2:
    b3:ea:27:f5:b3:cf:f6:0b:1a:d3:28:82:63:ef:53:
    ab:e4:d8:dc:c6:57:a7:ff:9d:35:80:a8:c6:35:af:
    9d:4c:62:e4:9c:d3:db:e9:07:ad:8d:9c:8a:85:c6:
    50:24:29:8b:da:7e:90:24:70:cf:0e:b4:15:46:8e:
    89:cd:24:e6:c6:b4:42:0e:13:b3:1d:3d:f8:87:52:
    70:2e:18:53:26:64:35:ed:16:9c:cd:23:f5:58:2f:
...
```



[2025] Clevo leak - Impacted Devices

Firmware / Device name	ODM	IBV	Version	Release date
XPG Xenia 15G G2303_V1.0.8	Clevo	Insyde	6.2.8320.0	2023-06-14
Gigabyte G5 KE	Clevo	Insyde	FB05	2023-03-07
Gigabyte G5 KF 2024	Clevo	Insyde	FD06	2024-01-10
Gigabyte G5 KF5 2024	Clevo	Insyde	FD10	2024-12-09
Gigabyte G5 ME	Clevo	Insyde	FB04	2023-06-05
Gigabyte G5 MF	Clevo	Insyde	FB03	2023-04-14
Gigabyte G6 KF	Clevo	Insyde	FB06	2023-10-23
Gigabyte G6X 9KG 2024	Clevo	Insyde	FB10	2025-02-04
Gigabyte G7 KF	Clevo	Insyde	FB10	2024-02-16
NoteBook Firmware 1.07.07TRO1	Clevo	Insyde	6.2.8319.7	2023-09-05
NoteBook Firmware 1.07.09TRO1	Clevo	Insyde	6.2.8319.9	2023-11-28

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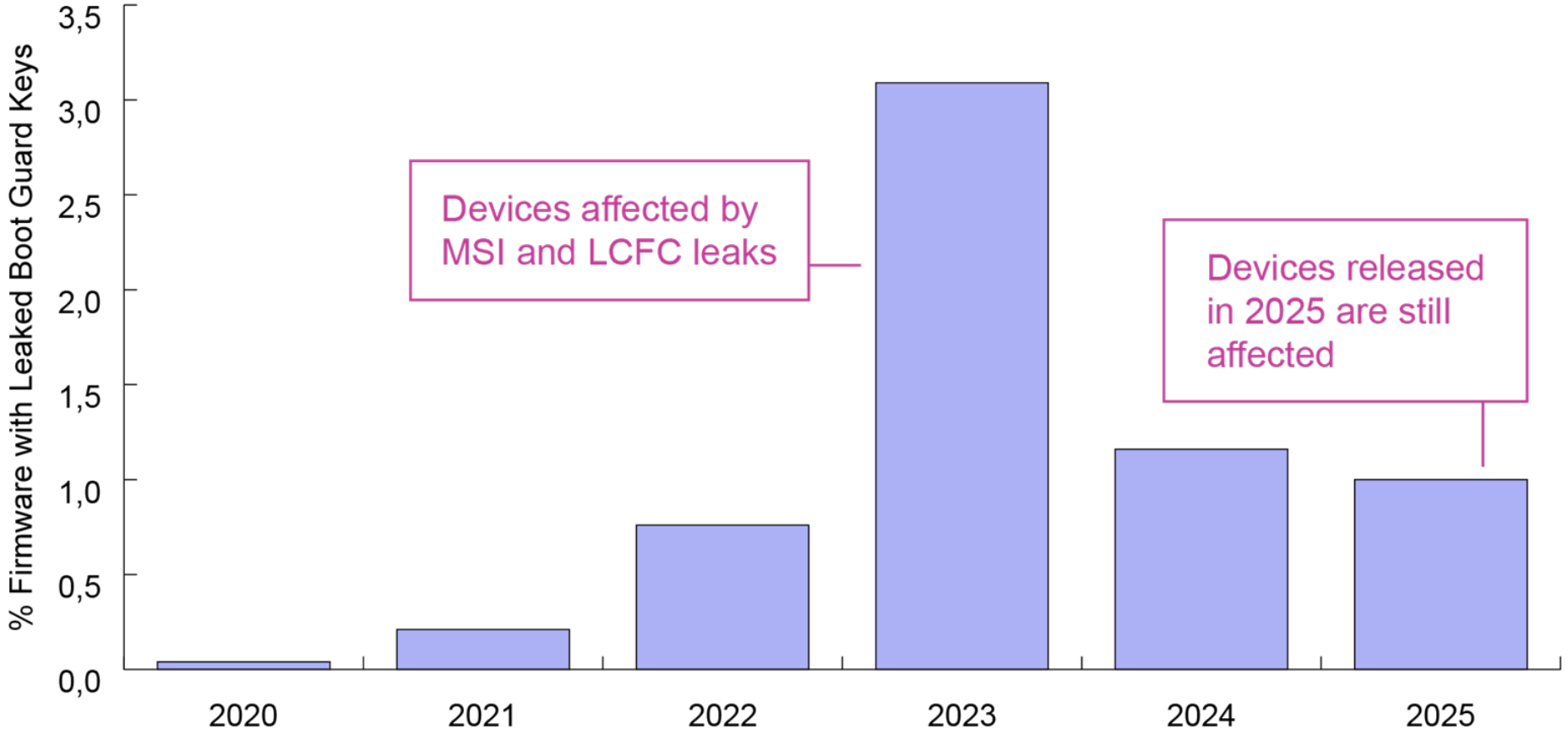
Intel Boot Guard
Impact of Leaked Keys

Boot Guard - Introduction

- Hardware-based technology intended to protect against execution of non-genuine UEFI firmware
- Multiple components and cryptographic keys involved:
  1. **Authenticated code module (ACM)**: Intel-signed code that runs before the firmware and cryptographically verifies the firmware
  2. **Key Manifest (KM)**: verifies Boot Policy Manifest
  3. **Boot Policy Manifest (BPM)**: verifies Initial Boot Block (basically, the firmware)

Impact of Boot Guard keys leakage



Impact of Boot Guard keys leakage

Why current devices are still vulnerable to a leak from years ago?

The Boot Guard Key Manifest hash is fused in the platform hardware and it **cannot** be changed!

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[2024] PKfail
Leaked Platform Key Story

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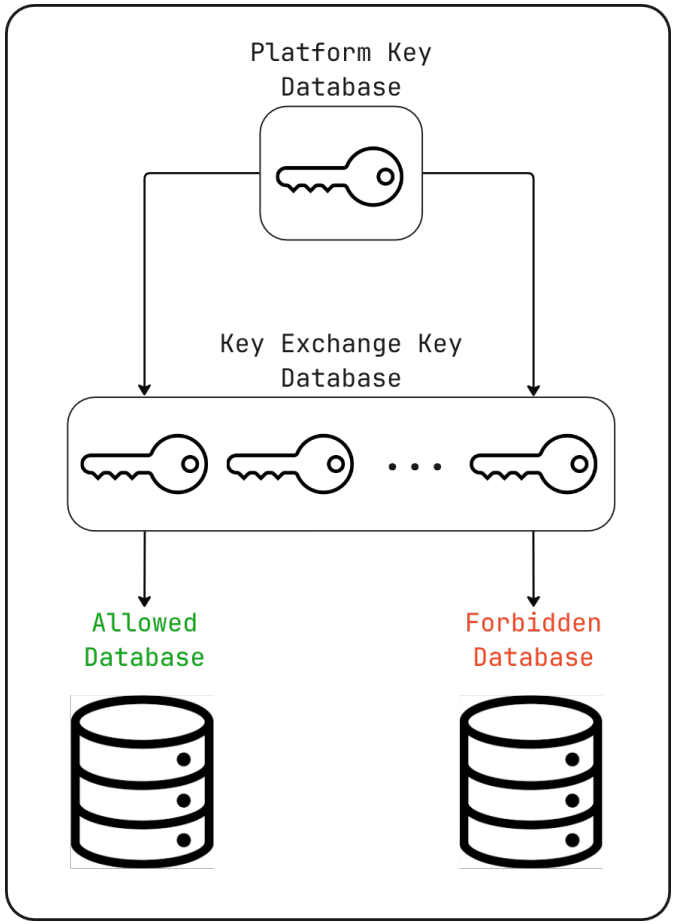
One Community.

UEFI Secure Boot

- Allows only trusted, digitally signed software to run during system startup, preventing malware and unauthorized code execution.
- Bypassing Secure Boot allows for bootkit and rootkit execution
- Four databases:
  - PK, KEK, db, dbx



[2024] PKFail

While adding support for Secure Boot to our Binarly Transparency Platform, we found an "*interesting*" Platform Key:

https://www.binarly.io/blog/pkfail-untrusted-platform-keys-undermine-secure-boot-on-uefi-ecosystem

```
Version: 3 (0x2)
Serial Number:
    55:fb:ef:87:81:23:00:84:47:17:0b:b3:cd:87:3a:f4
Signature Algorithm: sha256WithRSAEncryption
Issuer: CN=DO NOT TRUST - AMI Test PK
Validity
    Not Before: Nov  8 23:32:53 2017 GMT
    Not After : Nov  8 23:32:52 2021 GMT
Subject: CN=DO NOT TRUST - AMI Test PK
Subject Public Key Info:
    Public Key Algorithm: rsaEncryption
        Public-Key: (2048 bit)
        Modulus:
            00:e7:36:7b:20:92:ba:7f:aa:a3:f6:0e:49:08:87:
            f5:1c:11:33:ba:5d:f8:9b:5c:ed:c7:90:e4:f3:41:
...
```

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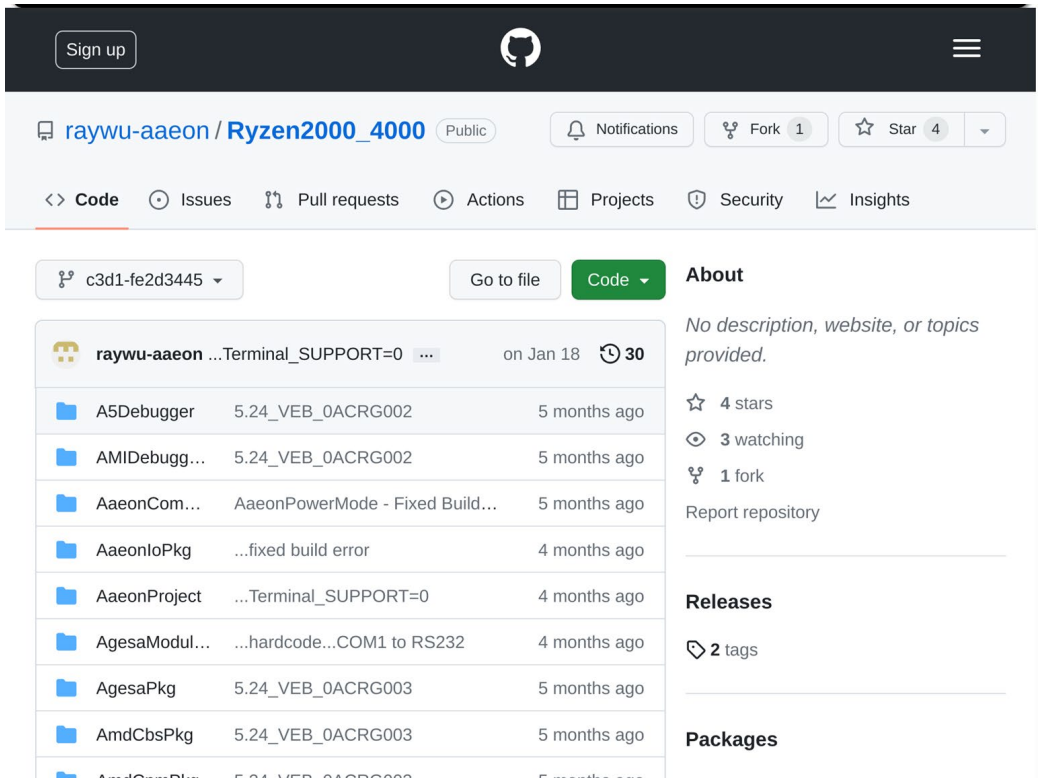
[2023] AAeon leak

- In January 2023, the repository **Ryzen2000_4000** is published on GitHub
- Contains IBV (AMI) reference implementation, ODM (AAeon) implementation and private keys
- Remained public until AMI sent a DMCA to GitHub in June 2023



[2023] AAeon leak

```
$ openssl x509 -noout -text -in FW_pubKey.cer  | rg "Issuer:|Subject:"
        Issuer: CN=DO NOT TRUST - AMI Test PK
        Subject: CN=DO NOT TRUST - AMI Test PK
```

```
$ openssl pkcs12 -in FW_priKey.pfx -nodes
Enter Import Password:
```

```
$ cat AmiTestKey.sdl | grep password -C3
TOKEN
        Name  = "FW_PFX_Password"
        Value  = "abcd"
        Help  = "Specifies the password to use when opening a PFX -
Private Key container file."
        TokenType = Expression
        TargetMAK = Yes
End
```

Oh, hi! I am a private key that's been available on GitHub for 6 months! 🤷‍♂️

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Retrospective view on PKFail

Dataset with 80,000 UEFI firmware images:

- Spanning over 10 years
- Includes every major vendor (Lenovo, Dell, HP, Intel..)

Results:

- 10% of images use non-production keys
- 8% of images when selecting images released in the past 4 years
- 22 unique non-production keys identified

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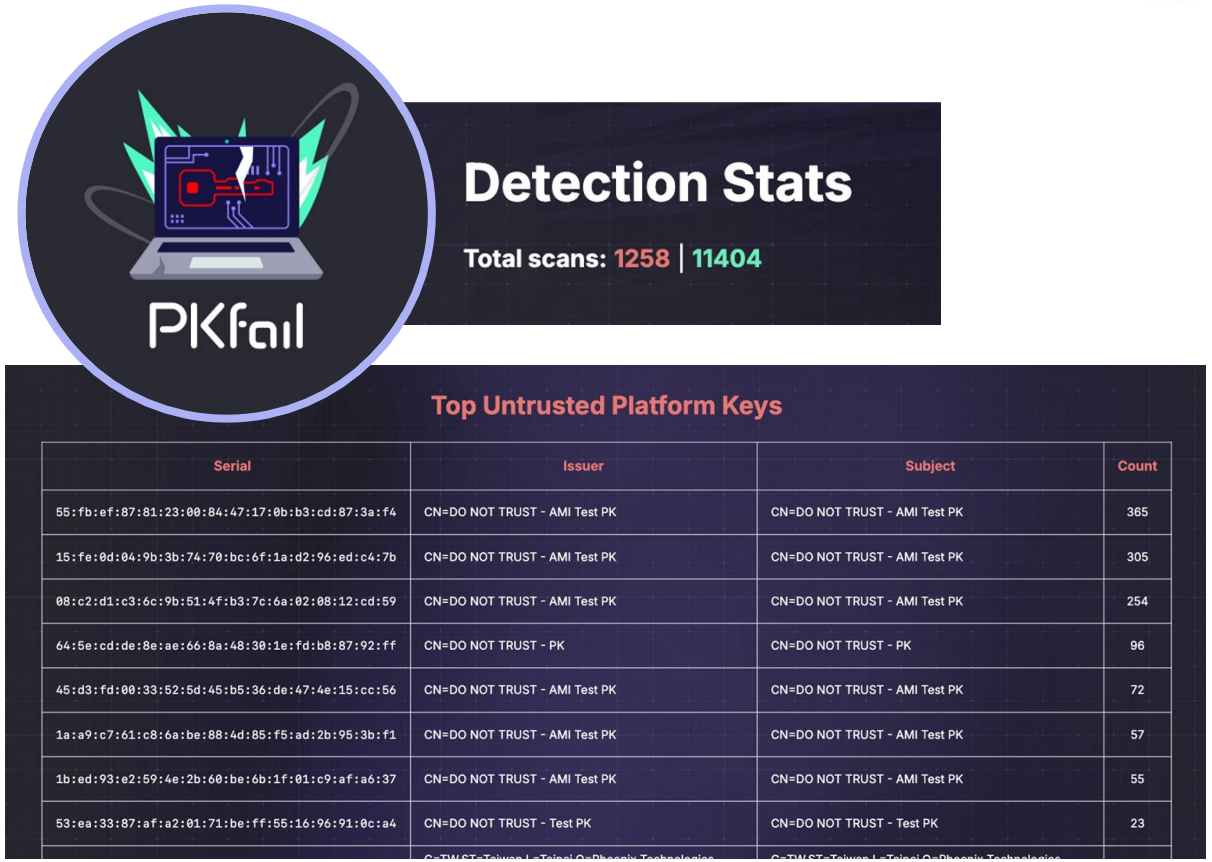
Retrospective view on PKFail

Certificate Serial Number	Certificate Subject	Certificate Issuer	Last Seen	First Seen	Products	Vendors
55:fb:ef:87:81:23:00:84:47:17:0b:b3:cd:87:3a:f4	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2024-06	2018-04	364	Acer, Dell, Fujitsu, Gigabyte, Intel, Lenovo, Supermicro
-08:c2:d1:c3:6c:9b:51:4f:b3:7c:6a:02:08:12:cd:59	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2024-06	2022-06	167	Acer, Dell, Gigabyte, Supermicro
-15:fe:0d:04:9b:3b:74:70:bc:6f:1a:d2:96:ed:c4:7b	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2024-03	2015-01	483	Acer, Dell, Gigabyte, Intel, Lenovo, Supermicro
-1b:ed:93:e2:59:4e:2b:60:be:6b:1f:01:c9:af:a6:37	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2023-01	2014-12	287	Dell, Fujitsu, Gigabyte, HP, Intel, Lenovo, Supermicro
1a:a9:c7:61:c8:6a:be:88:4d:85:f5:ad:2b:95:3b:f1	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2021-03	2012-05	157	Acer, Dell, Fujitsu, Gigabyte, HP, Lenovo, Samsung, Supermicro

Binarly's pk.fail detection service

Binarly released a free detection service for the community on disclosure date:

- Users uploaded **12,662** firmware images
- Found untrusted keys in **1,258** of them (9.94%)
- The most common key remains the leaked AMI key 🔥



Serial	Issuer	Subject	Count
55:fb:ef:87:81:23:00:84:47:17:0b:b3:cd:87:3a:f4	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	365
15:fe:0d:04:9b:3b:74:70:bc:6f:1a:d2:96:ed:c4:7b	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	305
08:c2:d1:c3:6c:9b:51:4f:b3:7c:6a:02:08:12:cd:59	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	254
64:5e:cd:de:8e:ae:66:8a:48:30:1e:fd:b8:87:92:ff	CN=DO NOT TRUST - PK	CN=DO NOT TRUST - PK	96
45:d3:fd:00:33:52:5d:45:b5:36:de:47:4e:15:cc:56	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	72
1a:a9:c7:61:c8:6a:be:88:4d:85:f5:ad:2b:95:3b:f1	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	57
1b:ed:93:e2:59:4e:2b:60:be:6b:1f:01:c9:af:a6:37	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	55
53:ea:33:87:af:a2:01:71:be:ff:55:16:96:91:0c:a4	CN=DO NOT TRUST - Test PK	CN=DO NOT TRUST - Test PK	23

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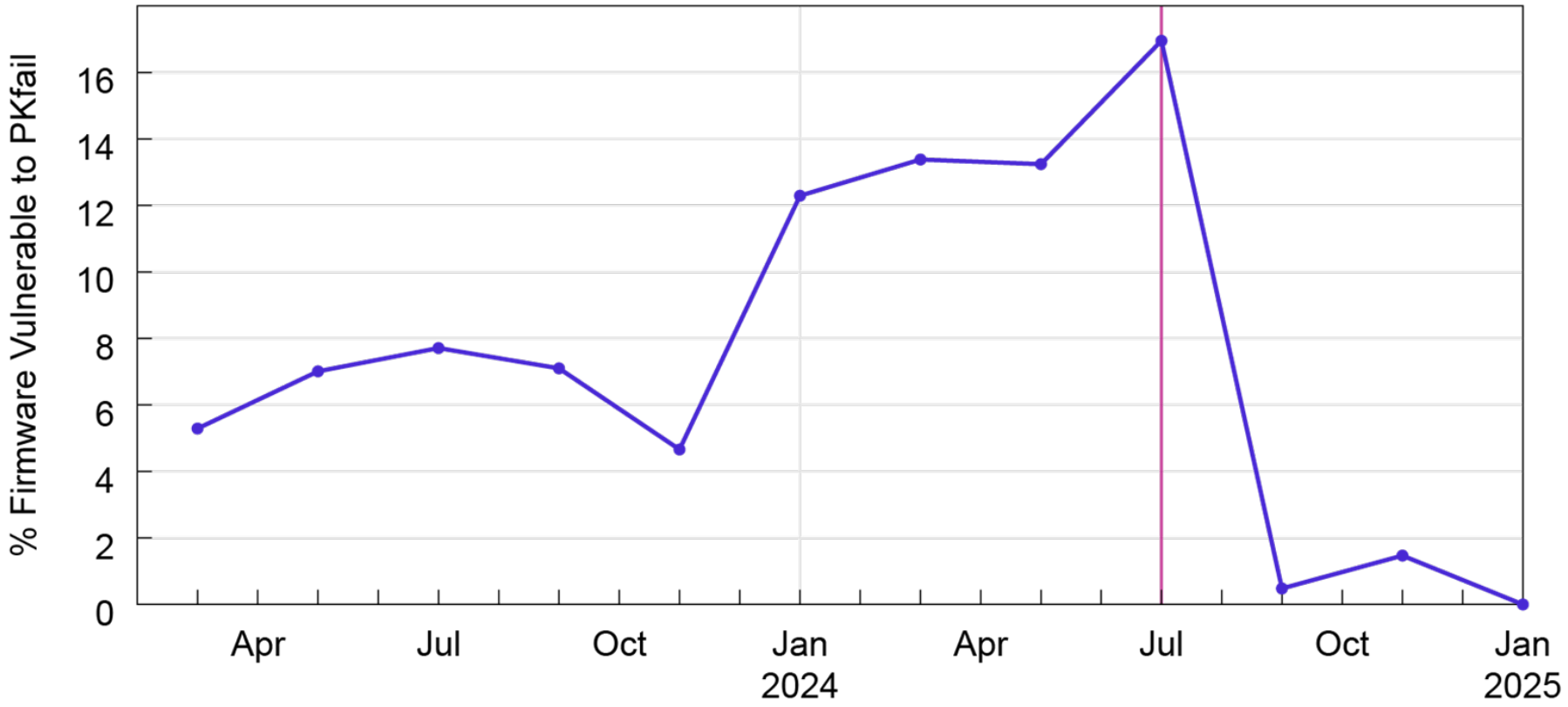
Impact of PKFail on the UEFI ecosystem



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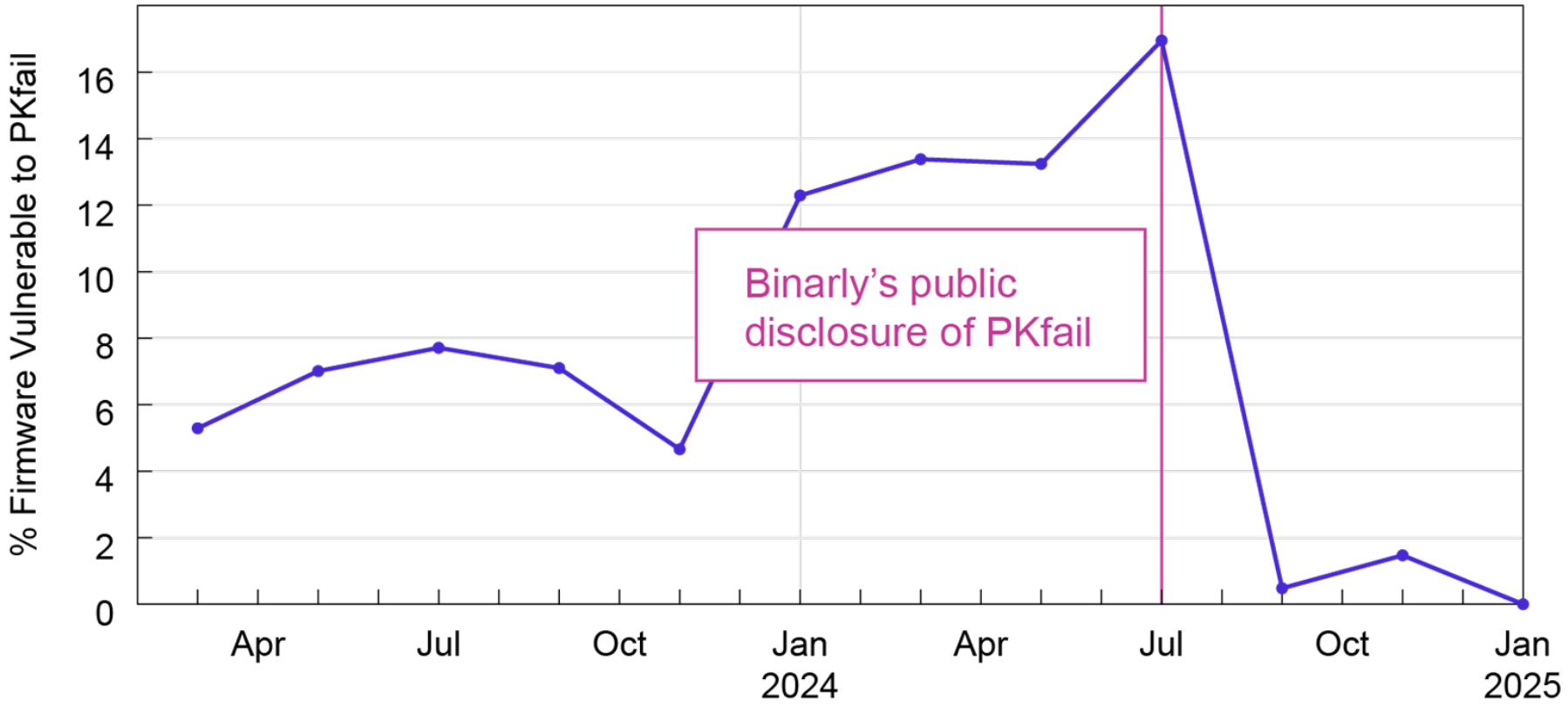
Impact of PKFail on the UEFI ecosystem



No firmware vulnerable to PKfail detected so far in 2025!

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Distribution of PK across vendors

	2021	2022	2023	2024	Total (Unique)
Acer	4	3	1	3	6
Dell	18	22	16	17	28
Fujitsu	5	7	8	6	9
Gigabyte	6	10	12	11	15
HP	3	3	3	3	3
HPE	2	2	2	2	2
Intel	5	10	5	1	10
Lenovo	37	106	120	92	154
Msi	4	5	5	3	5
Supermicro	3	3	3	1	4

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PKfail PoC

https://www.youtube.com/watch?v=SPl7zfC-CmQ

PKfail PoC (Linux)

https://www.youtube.com/watch?v=CveWt3gFQTE

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[2024] Supermicro BMC Test Key Reuse

[2024] Supermicro test key

- Baseboard Management Controller (BMC) firmware also affected by a similar problem
- Test key was not leaked
- Despite our report, nothing changed:
  - Public key modulus still present in the latest firmware images
  - Parts of the image is still signed with the test key

```
Version: 3 (0x2)
Serial Number:
    1a:da:e6:cf:23:66:6a:36:d9:dd:69:4c:2f:ba:30:14:90:f7:3d:5e
Signature Algorithm: sha512WithRSAEncryption
Issuer: C = US, ST = CA, L = SanJose, O = Super Micro Computer Inc.,
        CN = RD1 BMC Test Key - DO NOT TRUST
Validity
    Not Before: Feb 14 03:14:28 2020 GMT
    Not After : Feb  1 03:14:28 2070 GMT
Subject: C = US, ST = CA, L = SanJose, O = Super Micro Computer
Inc.,
        CN = RD1 BMC Test Key - DO NOT TRUST
Subject Public Key Info:
    Public Key Algorithm: rsaEncryption
        Public-Key: (4096 bit)
        Modulus:
            00:c6:b3:42:c9:36:c3:a1:24:0c:ec:e5:1a:31:96:
            5b:1d:a6:c7:85:66:50:bf:59:78:9c:2d:8d:07:5e:
            6f:9b:f0:a0:70:7a:42:f0:0a:68:bd:e1:aa:80:ef:
            2c:70:bd:7a:36:59:6a:ca:2a:1d:21:f1:1c:a1:31:
...
```

https://www.binarly.io/blog/repeatable-failures-test-keys-used-to-sign-production-software-again

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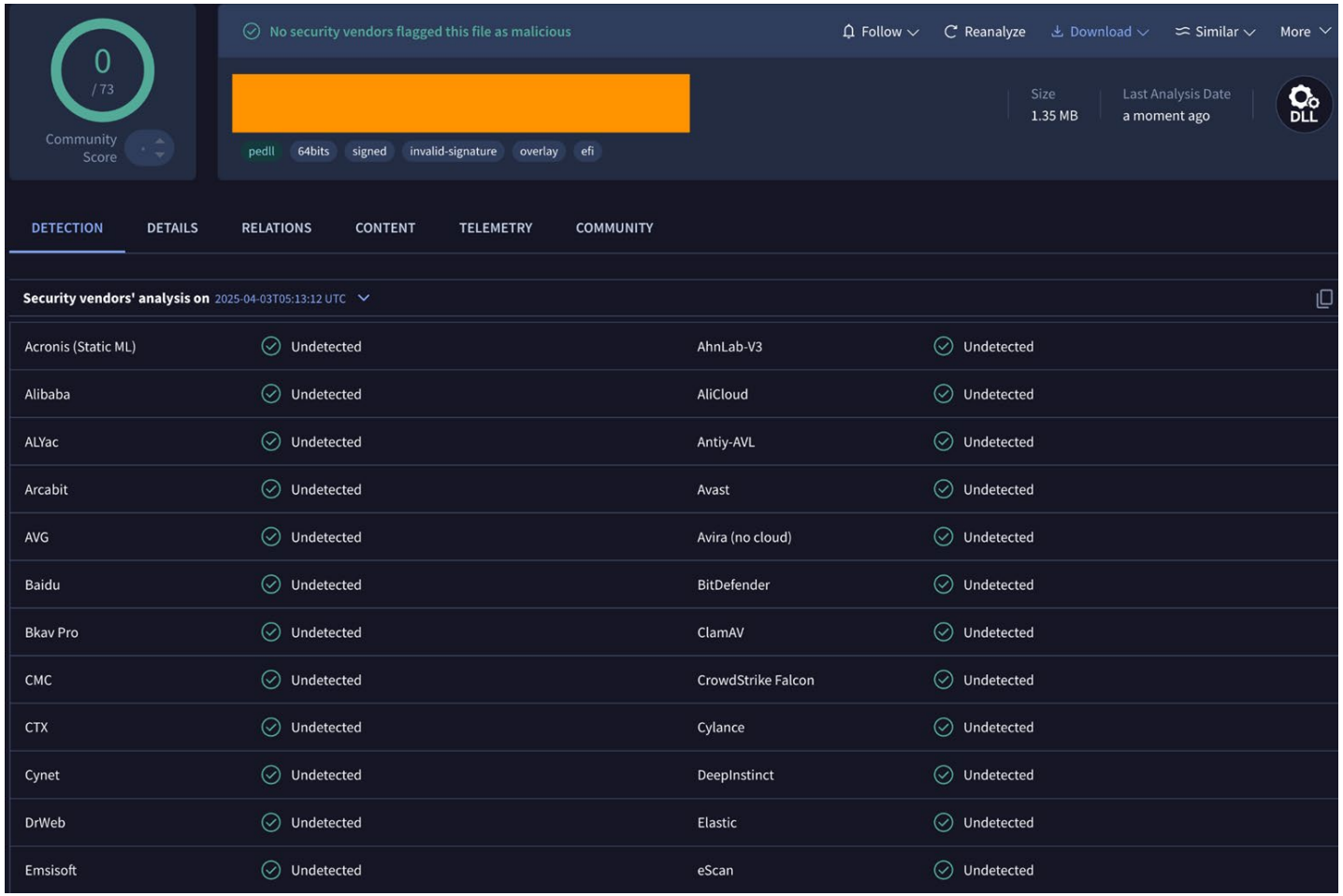
[2025] Microsoft Signed UEFI Module Universal Secure Boot Bypass CVE-2025-3052 (BYOVD)

[2025] SignedModule.efi found on VT



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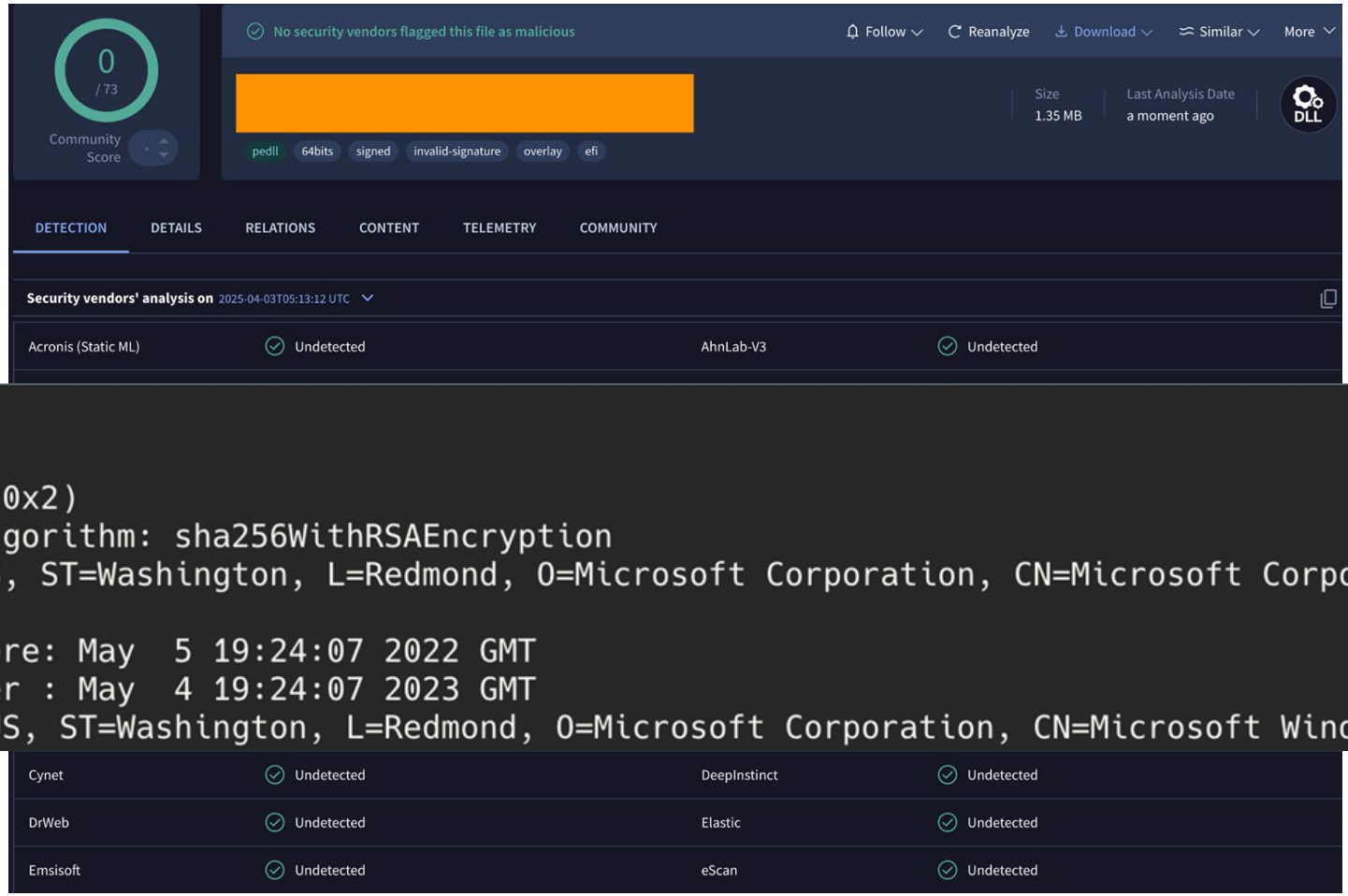
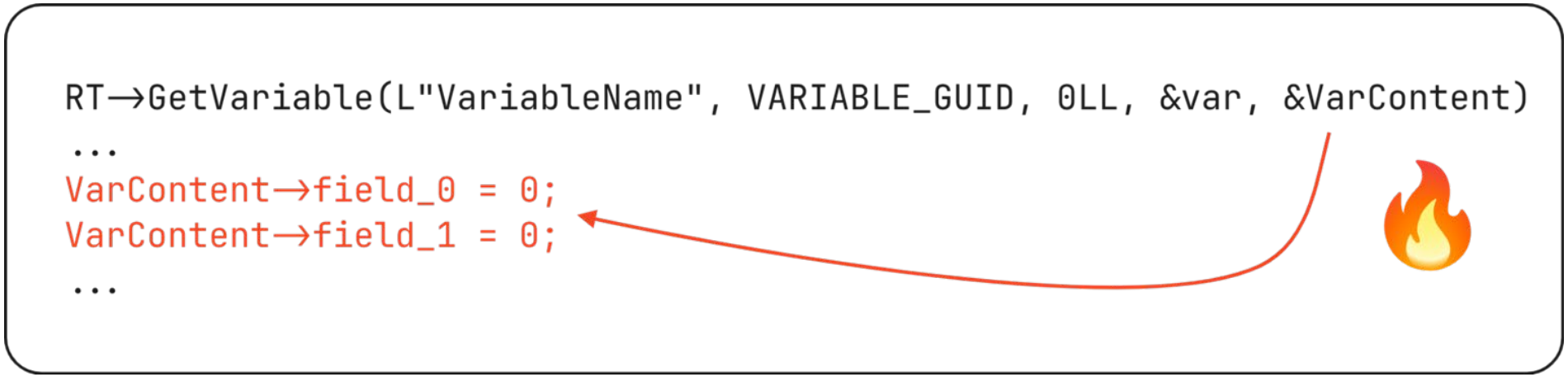
[2025] SignedModule.efi found on VT



[2025] SignedModule.efi found on VT

- Secure Boot is prone to BYOVD attacks
- Ongoing disclosure with CERT//CC (*stay tuned for more details…*)
- Module signed with “Microsoft Corporation UEFI CA 2011”, trusted by basically every device out there



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DEMO
Proof of Concept for CVE-2025-3052

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[2025] DBX Inconsistency Another Secure Boot bypass

[2025] DBX Inconsistency

- dbx is a crucial component of Secure Boot: it contains what **must not be trusted**
- Single source of truth for the entire ecosystem: UEFI Forum
- In July 2024, Microsoft publishes the DBX2024 update, blocking modules related to CVE-2024-28924 (Secure Boot Bypass)
- This update wasn't included in the UEFI Forum's dbx, so the update didn't propagate to non-MS devices (e.g. LVFS)
- For around 6 months, a Secure Boot bypass has been publicly known but not included in non-MS dbx

https://www.binarly.io/blog/from-trust-to-trouble-the-supply-chain-implications-of-a-broken-dbx

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Secure Boot bypass + Bootkit = ☠

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AMD Microcode
Broken Signature Validation

[2025] EntrySign (CVE-2024-56161)

- Google researchers found an AMD microcode vulnerability that allows crafting valid microcode updates
- The microcode controls the low-level operations of the CPU:
  - Allows to override any CPU instruction (rdrand always returns 4)
  - Very difficult to detect, it basically infects the CPU
- Root cause: *"We noticed that the key from an old Zen 1 CPU was the example key of the NIST SP 800-38B publication and was reused until at least Zen 4 CPUs".*

https://bughunters.google.com/blog/5424842357473280/zen-and-the-art-of-microcode-hacking
https://www.binarly.io/blog/binarly-tracking-updates-for-cve-2024-56161-a-high-risk-microcode-flaw-in-amd-cpus

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Post Quantum Readiness
Device Security Implications

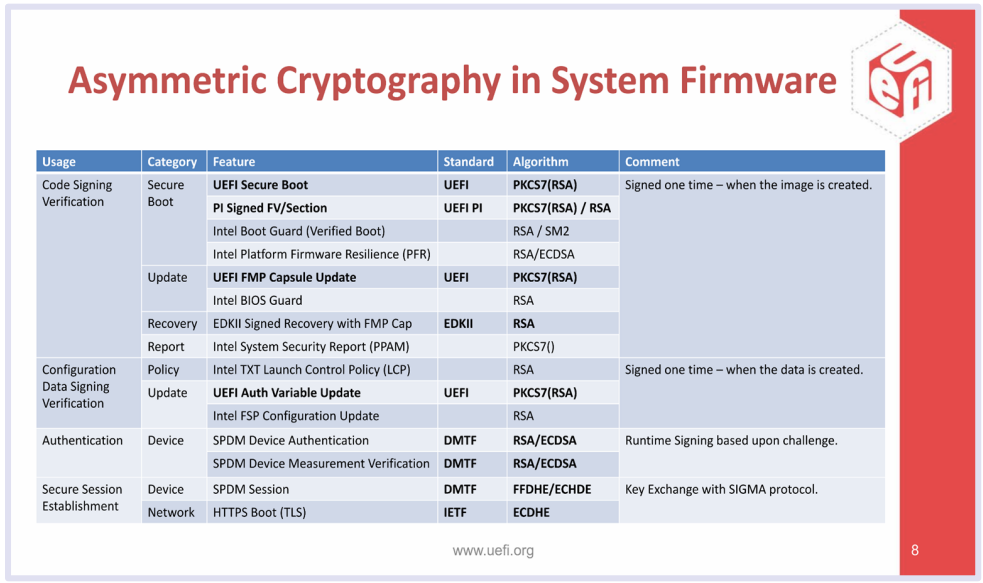
Post-Quantum Readiness

*"The migration will take time and will be more complex than people think. This is actually the driver. Even though **7–10 years sounds a long time** away, in reality the extent of the work needed might mean you are already too late."*

Phil Venables, CISO @ Google Cloud

https://www.philvenables.com/post/post-quantum-cryptography-migration-time-to-get-going

Post-Quantum Readiness in UEFI



Asymmetric Cryptography in System Firmware

Usage	Category	Feature	Standard	Algorithm	Comment
Code Signing Verification	Secure Boot	**UEFI Secure Boot**	**UEFI**	**PKCS7(RSA)**	Signed one time – when the image is created.
		PI Signed FV/Section	**UEFI PI**	**PKCS7(RSA) / RSA**	
		Intel Boot Guard (Verified Boot)		RSA / SM2	
		Intel Platform Firmware Resilience (PFR)		RSA/ECDSA	
	Update	**UEFI FMP Capsule Update**	**UEFI**	**PKCS7(RSA)**	
		Intel BIOS Guard		RSA	
	Recovery	EDKII Signed Recovery with FMP Cap	**EDKII**	**RSA**	
	Report	Intel System Security Report (PPAM)		PKCS7()	
Configuration Data Signing Verification	Policy	Intel TXT Launch Control Policy (LCP)		RSA	Signed one time – when the data is created.
	Update	**UEFI Auth Variable Update**	**UEFI**	**PKCS7(RSA)**	
		Intel FSP Configuration Update		RSA	
Authentication	Device	SPDM Device Authentication	**DMTF**	**RSA/ECDSA**	Runtime Signing based upon challenge.
		SPDM Device Measurement Verification	**DMTF**	**RSA/ECDSA**	
Secure Session Establishment	Device	SPDM Session	**DMTF**	**FFDHE/ECHDE**	Key Exchange with SIGMA protocol.
	Network	HTTPS Boot (TLS)	**IETF**	**ECDHE**	

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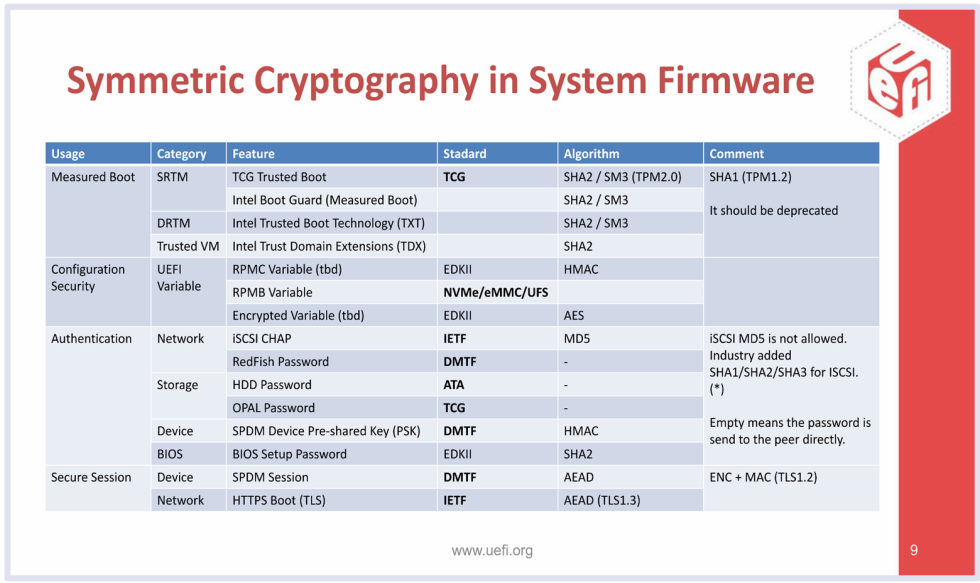

Symmetric Cryptography in System Firmware

Usage	Category	Feature	Stadard	Algorithm	Comment
Measured Boot	SRTM	TCG Trusted Boot	**TCG**	SHA2 / SM3 (TPM2.0)	SHA1 (TPM1.2)
		Intel Boot Guard (Measured Boot)		SHA2 / SM3	It should be deprecated
	DRTM	Intel Trusted Boot Technology (TXT)		SHA2 / SM3	
	Trusted VM	Intel Trust Domain Extensions (TDX)		SHA2	
Configuration Security	UEFI Variable	RPMC Variable (tbd)	EDKII	HMAC	
		RPMB Variable	**NVMe/eMMC/UFS**		
		Encrypted Variable (tbd)	EDKII	AES	
Authentication	Network	iSCSI CHAP	**IETF**	MD5	iSCSI MD5 is not allowed. Industry added SHA1/SHA2/SHA3 for ISCSI. (*)
		RedFish Password	**DMTF**	-	
	Storage	HDD Password	**ATA**	-	
		OPAL Password	**TCG**	-	Empty means the password is send to the peer directly.
	Device	SPDM Device Pre-shared Key (PSK)	**DMTF**	HMAC	
	BIOS	BIOS Setup Password	EDKII	SHA2	
Secure Session	Device	SPDM Session	**DMTF**	AEAD	ENC + MAC (TLS1.2)
	Network	HTTPS Boot (TLS)	**IETF**	AEAD (TLS1.3)	

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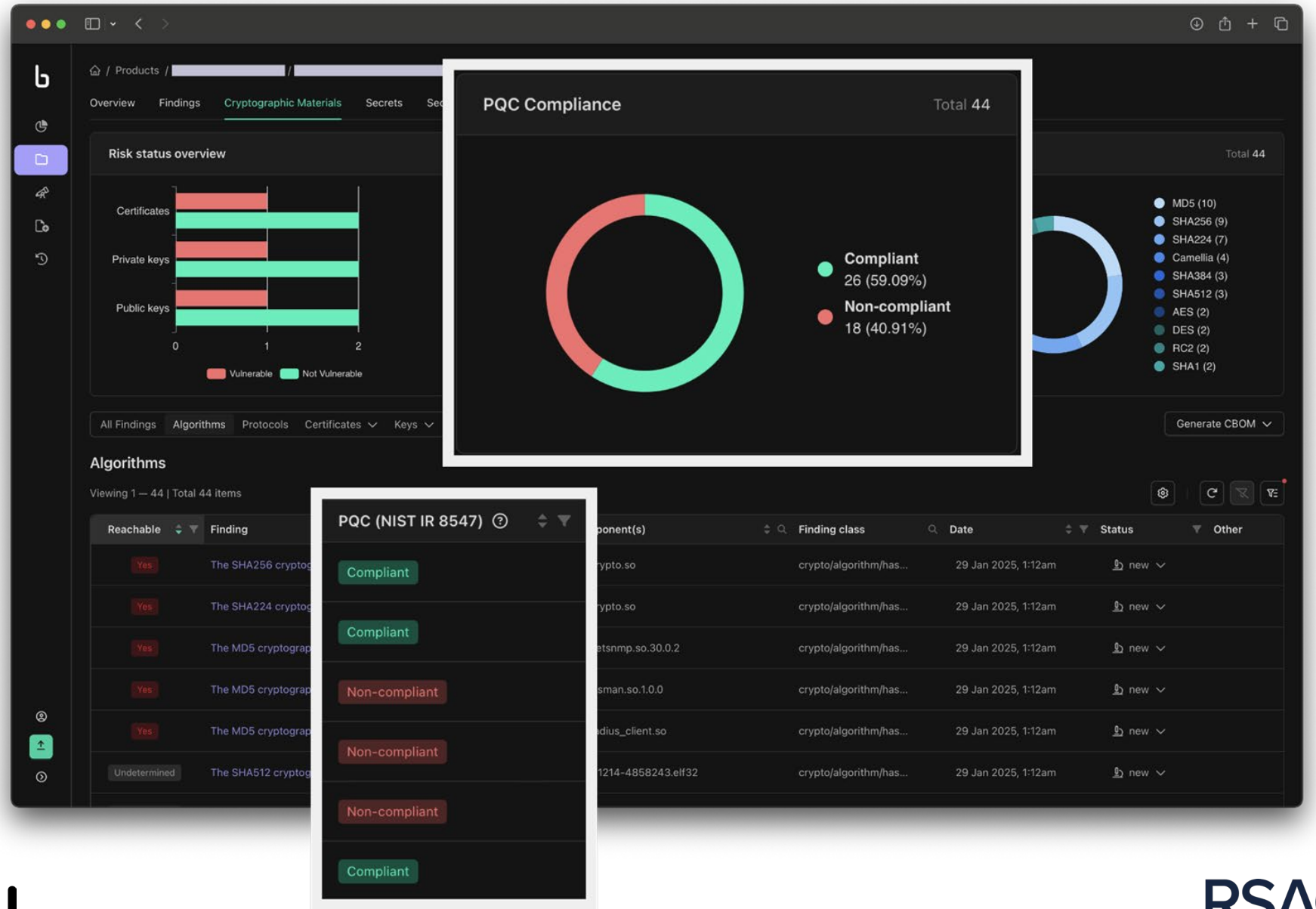
- Ongoing discussion and few proof-of-concepts
- It will take years to update every component (huge complexity in firmware)

Source: *Post Quantum Cryptography impact to the UEFI Firmware,* UEFI 2021 Virtual Plugfest


Products
Overview
Findings
Cryptographic Materials
Secrets
Risk status overview
Certificates
Private keys
Public keys
Vulnerable
Not Vulnerable
PQC Compliance
Total 44
Compliant
26 (59.09%)
Non-compliant
18 (40.91%)
MD5 (10)
SHA256 (9)
SHA224 (7)
Camellia (4)
SHA384 (3)
SHA512 (3)
AES (2)
DES (2)
RC2 (2)
SHA1 (2)
All Findings
Algorithms
Protocols
Certificates
Keys
Generate CBOM
Algorithms
Viewing 1 — 44 | Total 44 items
Reachable
Finding
PQC (NIST IR 8547)
Finding class
Date
Status
Other
Compliant
Compliant
Non-compliant
Non-compliant
Non-compliant
Compliant
29 Jan 2025, 1:12am
new

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All this has happened before.
All this will happen again.

Apply

- Make sure your UEFI firmware is always up-to-date
  - Bad news: that's one of the few things you can actually do
  - *Demand* better security practices from your UEFI firmware vendors
- Hope the vendor cares about security
  - Many don't, especially for older devices
  - Some can be opaque about firmware issues (especially unfixable ones!)
- Understand below-the-os OS security defenses (e.g. Secure Boot)
  - …and their limitations

Summary

- The UEFI firmware ecosystem has been affected by the leak of many private keys
- The intricate UEFI supply-chain exacerbates this problem
  - Keys leaked from vendor A can be deployed on devices from vendor B
- Poor cryptographic key management
  - Test keys intended for development end up in real devices
  - Private keys stored unencrypted or encrypted with weak and easily guessable passwords

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Thank you!

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One Community.